research review

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TARGET DETECTION USING SEQUENTIAL DESIGN

ALFRED CRANCER, JR., Directorate of Mathematical Sciences, AFOSR

In recently completed research sponsored by AFOSR, R. Bohrer of the Research Triangle Institute shows that the formulation of problems in sequential design of experiments is a generalization of conventional sequential analysis. In addition, he produces results analogous to standard sequential analysis and gives an example of the use of the theory in target detection.

The problem of target detection is solved in Chapter 3 of his paper. Suppose we wish to detect a target in a selected area by scanning with radar. The target may be located either to the north or south of our location, or there may be no target present at all. Because of interference, one radar reading will not give positive assurance of a target in a given area. The problem is to decide, based on the radar readings from the north or south, whether to fire at a supposed target or to collect further radar readings. As the number of radar readings increase, the uncertainty of the presence of a target decreases. However, each observation is made at a cost, so that action should be taken as soon as possible.

The problem is to determine the number of radar readings to take in light of the cost associated with each reading and losses associated with incorrect decisions. One solution would be to predetermine the number of readings beforehand. A second solution would be to allow the number of readings to vary depending on the costs and risks at the time of each observation.

An illustration of the risk associated with different solutions to this problem also is presented in Chapter 3. It is shown that, when we assume that the probability of a target in the north is .5, in the south is .1 (because of poor weather, etc.), and of no target at all is .4, then the sequential design formulation of the problem is superior to all other plans. For the example just given, we find that the sequential design risk may be as much as 18% lower than those associated with the best fixed sample-size plan. It is further stated that, for extremely high or low costs of making observations, the risks of most experimental designs are nearly equal--but for "moderate" costs, the sequentially designed experiment will be superior.

Only a portion of this research has been submitted for publication due to its length. However, copies of this research may be obtained by writing to the Mathematics Division, Directorate of Mathematical Sciences, AFOSR.

high-temperature chemical synthesis

MAJ. C. J. DONOVAN, Directorate of Engineering Sciences, AFOSR

A new field of basic inorganic chemistry was opened for investigation with the attempt to obtain chemical synthesis in the high-temperature environment of the plasma jet. This new facet of high-temperature chemistry was derived from a research program conducted by the Temple Research Foundation of Temple University under a grant from the AFOSR Propulsion Division.

The field of high-temperature chemistry and, in particular, flame chemistry, has been pioneered by Dr. A. V. Grosse and co-workers at the Temple Research Foundation. This group is credited with producing the hottest chemical flames, i.e., cyanogen oxygen, cyanogen-ozone, and carbon subnitride-oxygen with flame temperatures as high as 5,300 degrees Kelvin. Now, for the first time, chemical compounds have been synthesized using a high-intensity arc plasma jet for generating high temperatures (5,000° K to 20,000° K) beyond the range of chemical combustion flames and the ordinary electric arc.

The apparatus consists of a plasma generator with a 600-ampere d-c welder used as a power source and an attached reaction

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JACOB SEIDEN
Editor

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chamber fitted with a cold finger adjustable probe. The power source supplies a power input of up to 14 kilowatts to the plasma gas within the plasma generator. The design of the plasma generator consists of a water-cooled, one-eighth-inch thoriated tungsten cathode and a water-cooled copper anode separated and insulated from the cathode by a nylon case. The plasma gas is fed through an injector having equally spaced holes in the nylon case surrounding the cathode. A powder-feeding ring is placed between the anode and the reaction chamber, allowing gas-carried powder to be fed into the jet of the plasma where the chemical reaction takes place. The solid reaction products are collected on the cold finger probe which is immersed in the plasma fluid, and subsequently these products are analysed by means of X-ray diffraction.

Production yields of the compound synthesized in the plasma jet depend on the temperature achieved and the quenching rate, i.e., the distance of the adjustable cold finger probe from the powder-feed ring, which is a function of the residence time of the reactant in the plasma environment. Heat-flux measurements of the plasma range between 0.5 and 4.5 kilocalories per square centimeter per second. These values are four to five times those obtained in rocket motors, thereby indicating an environment suitable for conducting research studies for new refractory materials needed for future rocket-motor liners and nozzles.

Many reaction schemes can be carried out since the plasma jet can be operated using several different gases, for example, an inert gas such as helium which does not take part in the reaction, or a reactive gas such as nitrogen which forms a component of the reaction.

Several plasma jet chemical reactions have been studied in the past year. These have involved two types of reactions--the reaction of a solid and gas to yield a solid as the principal product, and the reaction of a solid and gas to yield a gas as the principal product.

As an example of the first type of reaction, the reduction of tantalum pentoxide (Ta_2O_5) to metallic tantalum has been accomplished by the use of a helium plasma jet whereby the oxide was carried into the jet with hydrogen and produced yields as high as 43% tantalum. Another example, the formation of tantalum carbide, was studied using two different approaches:

1. From tantalum pentoxide and methane.
2. From commercial tantalum metal powder and methane.

The first reaction produced yields of 24% tantalum carbide (TaC) and 17% ditantalum carbide (Ta_2C), depending on flow conditions, together with some metallic tantalum. The second reaction produced 72% TaC and 27% Ta_2C as a maximum under several different operating conditions.

The second type of reaction, the gas-solid reaction producing only a gas, proved more difficult, but the synthesis of hydrogen sulfide from the elements was successfully accomplished. The reaction was carried out in a helium-hydrogen plasma jet and yielded up to 37% hydrogen sulfide (H_2S), based on the sulfur input. The production of H_2S has been shown to be dependent on the enthalpy of the jet.

The formation of other refractory metal carbides and nitrides has also been accomplished in the plasma jet. Tungsten carbides have been obtained at very high yields by several methods, i.e., injecting tungsten metal, fluidized in a methane stream, into the "flame" of a helium jet; directly, from tungsten trioxide powder and methane by means of a helium plasma jet; also, in two steps, by the reaction of the product of the oxide reduction and methane in a helium jet. Yields as high as 100% titanium nitride (melting point--3,220°K) have been obtained by injecting titanium powder into the "flame" of the nitrogen plasma.

This unique method of synthetizing refractory metal nitrides and carbides is of utmost importance for the development of materials for various uses in high-temperature technology, and could eventually lead to the synthesis of new high-temperature-resisting alloys and compounds. These compounds are needed by the Air Force to raise the ever-limiting heat barrier resulting from increasing speeds and increasing temperatures found in advanced propulsion systems. ★

Plasma and The Plasma Sheath

JOHN C. CORBIN, JR., Plasma Physics Research Laboratory, ARL

According to Linhart (1), the word plasma first occurred in the term protoplasma which was originally introduced into scientific terminology in 1839 by the Czech biologist, Purkynic, to describe the jelly-like medium interspersed by numerous particles which constitutes the body of cells. In terms of blood, plasma is the residual material (fluid) left after removing the cellular elements. Langmuir (2) applied this term, plasma, to an ionized gas in which there are nearly equal numbers of electrons and ions. He pictured the positive ions as a rigid jelly in which the electrons were imbedded and free to move. We will use Langmuir's definition in our discussion of a plasma.

One might well ask: how is a plasma created? One way is to heat a gas in a container to a sufficiently high temperature so that the electrons break away from the neutral gas atoms or molecules, creating an assemblage of electrons, ions, and neutrals--the plasma. This process of ionization reaches an equilibrium when as many electrons are being freed as are recombining at the walls of the container or with the charged gas particles.

In the process of heating the gas, the average thermal energies acquired by the electrons and ions are equal. Because the mass of the lightest ion is about 1,836 times heavier than an electron, the average random velocity of the electrons must be much greater than that of the ions. As a consequence, the more mobile electrons tend to escape to the walls of the container, leaving an excess number of ions. This action sets up a potential difference (electric field) at the wall which tends to reflect most of the escaping electrons back into the plasma region. Thus, nearly equal numbers of electrons and ions are maintained in the main body of the plasma, while a charge unbalance exists in a thin surface layer at the container wall. The thickness of this layer--the sheath--is quite small, being 1 mm or less for the types of plasmas which can be created in the laboratory.

A detailed knowledge of the plasma sheath becomes quite important when one realizes that any measurement to determine the properties of a plasma, i.e., temperature, density, pressure, conductivity, viscosity, etc., must be done through the sheath. Further, the propagation of electromagnetic energy (waves) in a plasma is affected by the properties of the sheath. In some cases, energy losses through the sheath can be the principal source of attenuation for the waves.

Because of the paucity of information of the properties of the plasma sheath, the Plasma Physics Research Laboratory initiated a request for proposals in 1960 to study the static (dc) and dynamic (rf) properties of the sheath at the edge of a laboratory-generated plasma. A contract was awarded to Stanford University, and research was started in March 1961 in the W. W. Hansen Laboratories of Physics under the direction of G. S. Kino. Significant results achieved over a period of four years that the contract was in effect are described below.

A. Theory of the Static Sheath

In 1929, Tonks and Langmuir postulated a theoretical model for a low pressure dc discharge plasma for plane, cylindrical and spherical geometries. They termed the general integral equation for the potential distribution throughout the plasma and sheath as the "complete plasma sheath equation." By recognizing that charge neutrality is preserved to a high degree in the body of the plasma, they assumed exact charge neutrality and were able to reduce the complete plasma sheath equation to a simple integral equation which they termed the "plasma equation." They solved this equation for the cases of uniform ion generation and for ion generation proportional to electron density. While

their solution was a good approximation for the neutral plasma region, it became increasingly inaccurate as the boundary or sheath region was approached. To overcome this, they matched an approximate sheath solution onto the plasma solution. Again, the solution did not give the true potential profile in the plasma sheath transition.

S.A. Self of Stanford was able to extend this work by formulating an integral differential equation which takes into account unequal electron and ion densities. Numerical solutions were obtained which are valid all the way through the plasma and into the sheath. The static electric field in the sheath is accurately predicted, and the plasma density at the center of the discharge can be determined from the maximum field gradient in the sheath. It was found that the static potential variation within the sheath is almost parabolic. Consequently, the transit time of an electron into the sheath and out again is essentially independent of the velocity of the electron.

B. Dynamic Properties of the Plasma Sheath

A theoretical study of the dynamic characteristics of the sheath tends to be difficult because any simplified approach seems to be inadequate to properly describe the sheath. J. M. Pavkovich and G. S. Kino evaluated several simplified approaches with unsatisfactory results. They found the only approach which satisfactorily describes the sheath is one which integrates the complete collisionless Boltzmann equation. This equation takes into account (over a small volume) any gain or loss of particles, all particle energies, any changes in particle energies due to outside influences, and neglects collisional effects. They made the following assumptions to simplify the integration: (1) the rf motion of the ions can be neglected; (2) the static electron distribution is Maxwellian; (3) variation of quantities in a direction parallel to the sheath is slow enough to use a one-dimensional analysis; (4) the magnetic field can be neglected; and (5) the potential in the sheath has a parabolic variation. With an rf field applied external to the plasma, they found that pressure waves (called Bohm and Gross waves), near the sheath, are set up if the electric field is at a frequency above the plasma frequency (the frequency at which the plasma electrons oscillate about the ions). These waves propagate into the plasma for some distance, although they are damped (due to a resistive component of the impedance if the plasma is treated as a dielectric). If the electric field is at a frequency below the plasma frequency, waves which are excited at the sheath boundary have a rapid exponential decay. Damping is extremely small at frequencies very close to the plasma frequency; however, none of the computations revealed the occurrence of oscillations in the sheath.

C. Experimental Measurements of the Plasma Sheath

After theories were developed for the static and dynamic properties of the plasma sheath, an experimental program to measure dc and rf fields within the sheath was undertaken by R. S. Harp. Using a low-density plasma discharge of the order of 100 M Hz plasma frequency, a sheath thickness of about one centimeter was obtained. (Figure 1 illustrates the experimental arrangement.) The sheath to be measured was formed on a flat metal plate. The fields within the sheath were measured by passing an electron beam parallel to the plate and determining its deflection. By moving the plate, fields at any part of the sheath could be sampled. Special techniques were developed to measure fields as low as 0.1 volt cm and to determine both amplitude and phase of the signal within the sheath.

Experimental measurements of the dc field within the sheath agreed well with the theory of Self. The potential variation within the sheath was found to be nearly parabolic. No self-induced oscillations were observed within the sheath. When an rf potential was applied to the metal plate, fields within the sheath could be determined. The agreement between the Pavkovich-Kino theory and experiment was excellent. The experimental fields tend to fall off at a distance from the plate more rapidly than the theory predicts,

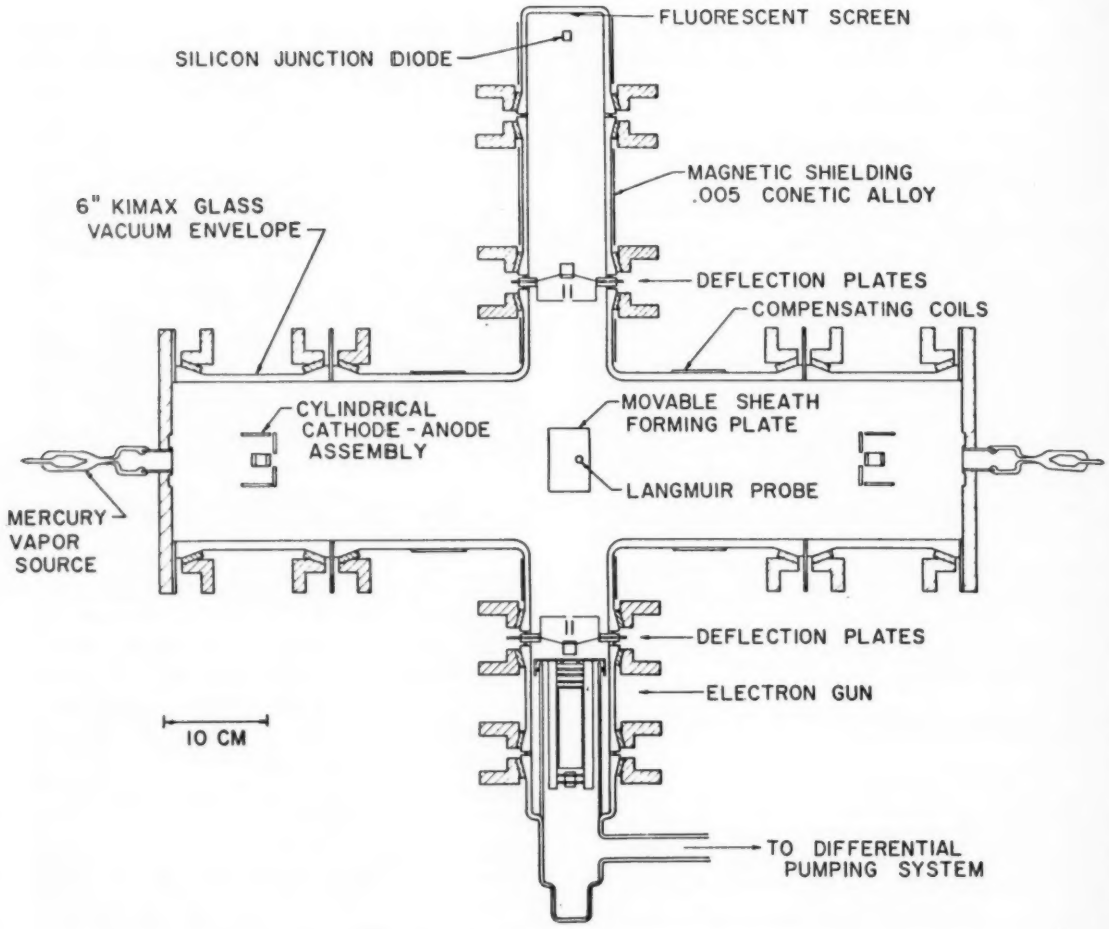

Fig. 1. A Schematic of the Experimental Apparatus.

but this is because the plate is not infinite as is assumed in the theory.

D. The Resonance Probe

Conventional (Langmuir) probe techniques have been used for many years to measure plasma electron temperature and density despite their limitations and uncertainties. Recently a plasma resonance probe has been studied which offers several advantages over conventional techniques.

The operation of the probe is based on an rf resonance in the sheath surrounding the probe. For frequencies below the plasma frequency, the field in the sheath is of opposite sign to that within the plasma being probed. Consequently, the integral of the total field from the probe out to infinity (i.e., the potential) will be zero at one particular frequency (resonance) although the fields within the sheath and plasma are finite.

R. S. Harp and F. W. Crawford developed a simplified theoretical model to describe the behavior of the resonance probe. Earlier published work indicated that resonance occurs at the electron plasma frequency and

is independent of probe potential. Both of these conclusions were found to be in error. They were able to predict when the resonance of the sheath would occur, at typically 0.6 the electron plasma frequency for the cases they examined using spherical probes. Moreover, they observed that the rectified dc probe current exhibits a resonant increase at rf resonance. Ringing of the probe was observed when a pulsed signal is applied to it, the ringing occurring at the predicted resonant frequency. They predicted and found that the resonant frequency depends on the ratio of probe diameter to sheath thickness; the smaller the probe, the nearer the resonant frequency to the plasma frequency. Also, they found that damping increases as the resonant frequency approaches the plasma frequency. They found that the resonant frequency is affected by the presence of a magnetic field, thereby making the probe less suitable than was first predicted for determining electron densities in ionospheric applications. However, the technique provides a means of making electron density measurements in high-speed transient discharges where conventional Langmuir probes are not suitable.

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EROSION JETS: NEWLY OBSERVED PHENOMENON

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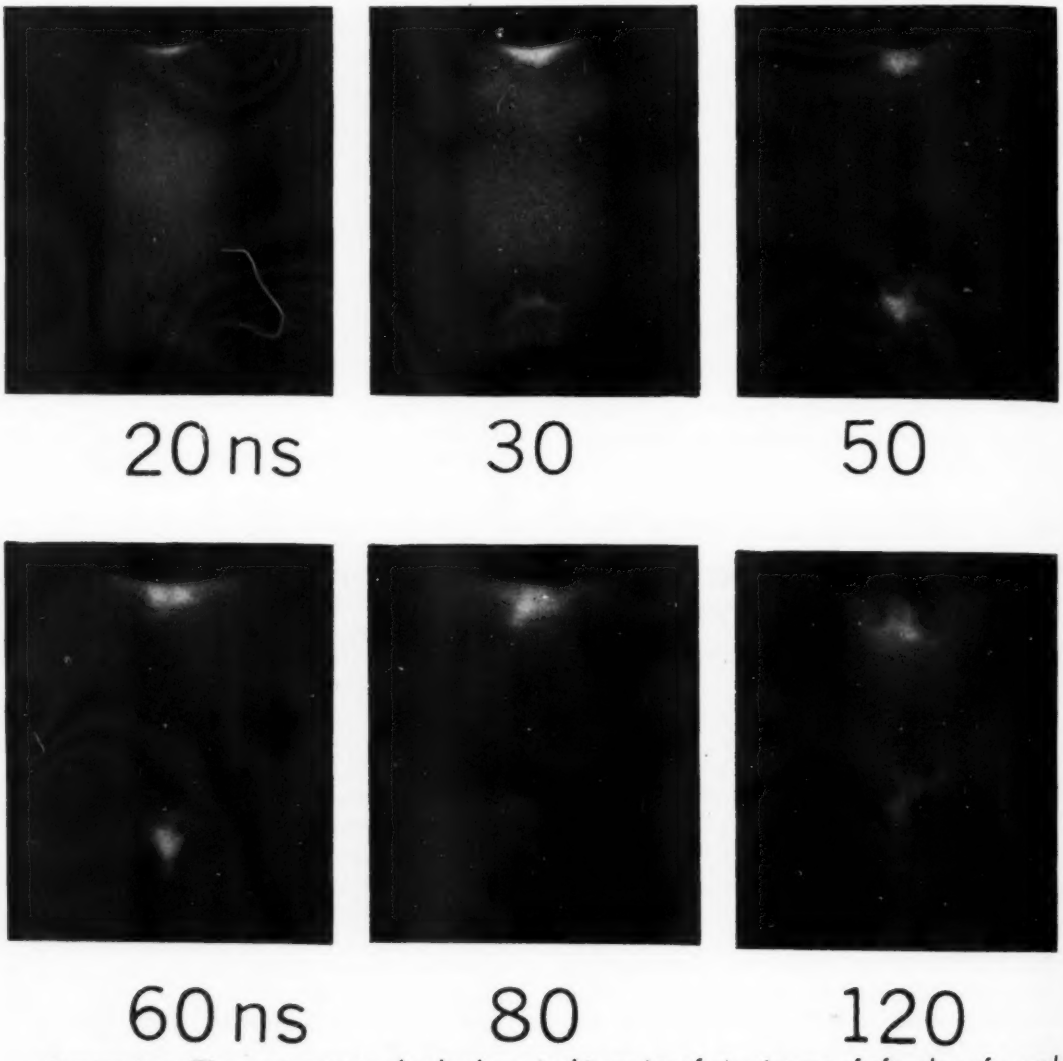
When a current jumps across the air gap from a cathode to an anode, the resultant spark discharge usually erodes both the cathode and the anode through simple thermal evaporation. Recently, an AFCRL scientist observed another erosion process--one predicted, but never before seen.

The phenomenon was first observed in the afterglow of a high-current, plasma light source, called the "Nanolite," developed by Dr. Heinz Fischer of AFCRL. The Nanolite produces extremely brilliant pulsed light with a duration measured in nanoseconds (billionths of a second). Photographs of the afterglow of the spark discharge showed that, at approximately 30 nanoseconds after the current had ceased, a jet of material literally explodes from a small, discrete point on the surface of the anode. This jet, lasting about 120 nanoseconds, resembles a water fountain--or, to some extent, the mushroom cloud of a microscopic atomic explosion.

Although this effect has not been previously observed, theory predicts that a fountain of material could be ejected from the tip of the anode as a result of "electron overpressure." Electron overpressure, an explosive condition resulting from too many electrons being squeezed into a small volume, could occur in an arc lamp's anode immediately after a flash. Such an explosive excess of electrons would likely build up in the anode of the light source because of its small diameter (0.05 millimeter) and the large current of several thousand amperes which flows from cathode to anode in a few nanoseconds. As the concentration of electrons expands, it knocks out minute chunks of elec-

trode material. Because of the short current times, small amounts of material are ejected; its effect on the useful lifetime of the electrode, though as yet undetermined, is probably small.

Evidence that the fountain-like ejection discovered by Dr. Fischer is the result of electron overpressure, however, is indirect. Emission spectra taken of the clouds have not shown any lines characteristic of the electrode element. (Copper and tungsten have been used.) This lack of spectral lines indicates that the material in the clouds is not in the vapor state. Thus, the fountain-like clouds are different from the usual form of electrode erosion in which material from the electrode surface is vaporized by the high temperature generated by the passage of electric current. In Dr. Fischer's experiments with the Nanolite, the current pulses, which lasted only 10 nanoseconds, were much



Erosion Jets. *The erosion jet is clearly shown in this series of six pictures of afterglow of a spark discharge. The entire sequence lasts about 100 nanoseconds (100 billionth of a second). The jet occurs after the current has ceased.*

too short to cause vaporization of electrode material. In future experiments, Dr. Fischer plans to use other electrode materials, which vaporize at low temperatures. In this way, he hopes to demonstrate by spectrographic techniques that the clouds do consist of material erupting from the anode.

The predominance of electrode evaporation in arc lamps is one of the reasons why the effect which Dr. Fischer discovered had not been observed before. It was only with the development of a virtually inductance-free capacitor, another effort which Dr. Fischer pioneered, that a high-current pulse lasting only nanoseconds could be discharged through an arc channel, thus eliminating electrode evaporation.

The discovery of such electrode erosion processes could have a bearing on certain studies of controlled thermonuclear power. Several devices now being studied make use of high-current discharges to heat the deuterium plasma. Even the slightest contamination of this plasma by impurities can cause an intolerably high loss of thermal energy through radiation by the contaminating material. Contaminating material could be introduced into the plasma by electrode erosion caused by electron overpressure. ★

COLD EXPLOSIONS

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Most common explosions are hot; thus, people equate the word, explosion, with searing heat. However, cold explosions do exist, and one such cold explosion is being investigated by AFOSR grantee Dr. Edward Bair at Indiana University. He is studying the cold explosion of ozone using a new and unique flash-photolysis-spectroscopic technique. In this method, Dr. Bair can directly study energy-transfer events in the gaseous phase during the explosion.

A useful combustion or explosion occurs when energetic substances react, liberate heat, cause gas to expand and do work. However, kinetic energy, which causes the expansion, is not necessarily the energy form which makes the reaction rapid and spontaneous. In order to break bonds and form active molecular fragments which promote the reaction, molecules must acquire vibrational energy. On the other hand, unless the vibrational energy is eventually converted to kinetic energy, it cannot contribute useful work. The practical efficiency of an energy-producing reaction is, therefore, crucially dependent on the nature and timing of these energy-transfer processes.

In the ignition stage, a small portion of an ozone sample is decomposed, giving oxygen atoms. An induction period of several microseconds follows during which the atoms decompose more ozone to give oxygen molecules, which have a large amount of vibrational energy. A sequence of separate bands of the oxygen spectrum shows the distribution of this vibrational energy during the remainder of the reaction while the intensity pattern of the individual lines in each band gives the kinetic-energy temperature of the system, which remains very close to the ambient room temperature throughout the entire chemical reaction period, about 100 microseconds. As soon as vibrationally excited oxygen is formed, it begins a vibration-to-vibration transfer of energy to the ozone. This is observed by the build-up of new bands in the long wave-length region of the ozone absorption spectrum. If the ignition has been adequate, a small portion of the ozone will acquire more vibrational energy than it can hold, and will dissociate to give more atoms which carry on the explosion.

Though kinetically cold, the oxygen may at times have as much vibrational energy as it would be expected to have at 8,000-10,000°K. After the ozone has been destroyed, this energy is then converted somewhat more slowly to kinetic energy, and the temperature and pressure rise, as expected.

At this point it is not clear whether a "cold explosion" is the exception or the (usually obscured) rule in normal combustion. In either case it has provided a valuable simplification for isolated study of the important steps of the process of combustion. ★

molecular interactions of polymers

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Lord Rayleigh first explained that the sky's blue color results from the scattering of light by single molecules of the air. Mathematical relationships between observed incident and scattered light made it possible to experimentally determine the number of molecules in a given volume of a gas. Early after the start of World War II, in connection with "rubber research," Nobel Laureate Dr. Peter Debye at Cornell University recognized that the measured scattering of light could be used for determining the number of solute particles in solution. Thus, light scattering became a tremendously important tool for measuring molecular weights of polymers.

When solute molecules are infinitely small compared to the wave length of the incident light, their size can be neglected in relating the intensity of scattered light to the molecular weight of the solute. For the higher molecular weight polymeric molecules, there is a general decrease of scatter intensity with increasing angle of scattering (or increased angular dissymmetry) since light scattered from different parts of the particle reaches the point of observation with phase differences. Since polymer molecules have no rigid geometrical structure, what is actually observed is an effect averaged over all the different forms that such a molecule assumes in the course of time. Hence, there is a smooth decrease of intensity with increasing angle between primary and secondary beams, as shown in Figure 1. The larger the average size of the molecule, the more rapid this decrease becomes.

Encouraged during the past few years by grant support from the Directorate of Chemical Sciences, AFOSR, Dr. Debye has been studying the interaction of molecules in solution by extending the light-scattering technique. His attention has been directed to the study of two component mixtures at temperatures near the critical opalescence point--the critical point for separation of two liquids, or a solid and a liquid, into two phases. At the vicinity of the critical point, thermal fluctuations of concentration, along with fluctuations of refractive index, are large. Consequently, the scatter intensity is large because here the work necessary to perform finite concentration change is very small.

When the experiment is performed with visible light and near the critical point, angular dissymmetry appears even for mixtures consisting of small molecules which, by themselves, because of their small dimensions, would never be able to show the dissymmetry effect. This effect now meas-

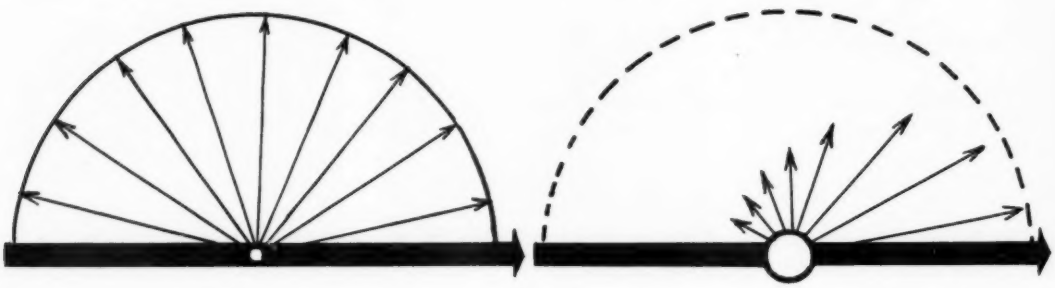

Figure 1

The light scattered by small particles has the same intensity in all directions whereas, in the case of larger particles, more light is scattered in the forward direction. In this sketch, the primary light is supposed to be polarized, with its electric vector perpendicular to the plane of the paper.

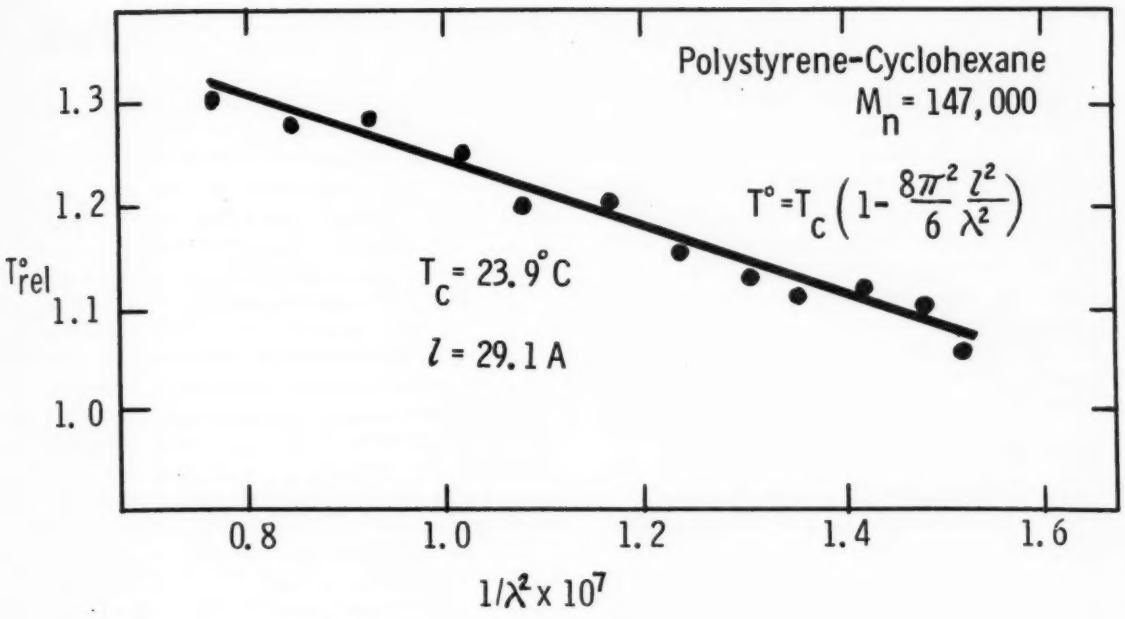

Figure 2

The apparent critical temperature plotted against $1/\lambda^2$ is a straight line which, by its slope, reveals the interaction range.

ures the coarseness of the fluctuation structure, and this coarseness becomes more pronounced as the critical point is approached. It turns out that the length (the correlation length) which measures this coarseness, and which can be calculated from the observed angular dissymmetry, is proportional to the average range of molecular forces. For a polymer such as styrene in cyclohexane, Dr. Debye found that the average range of interaction increased from 24Å to 50Å, with the molecular weight changing from 69,000 to 1,000,000, as compared with average ranges of the order of 10Å for small molecules such as methyl alcohol and benzene (when visible light with a wave length of the order of magnitude of 3,000Å was used). Another method for measuring this range is to observe the apparent dependence of the critical temperature on the color of the light used.

The average value for the interaction range of polystyrene was especially interesting because it seemed relatively small for the high molecular weight in question. This stimulated the desire to obtain more experimental detail in the scattering curve in order to learn more about the molecular interactions. One way to secure such information is to carry out experiments much nearer the critical temperature. However, in the case of polymers, the samples are never monomolecular, and available molecular-weight fractions are not nearly sharp enough. To obtain purer fractions would be both time-consuming and costly. A second way of getting the more detailed information is to use light with a much shorter wave length than visible light.

Dr. Debye recently approached the problem in the latter manner by using X rays with wave lengths a few thousand times smaller than that of light. Early results on a non-polymeric binary liquid mixture of perfluorotributyl amine and isopentane appear encouraging. The results have appeared in the November 1964 issue of the Journal of

Chemical Physics (41, No. 10, 3051-4). Also, small angle X-ray scattering measurements on polystyrene in cyclohexane have been completed, and will be published soon.

Dr. Debye's research on the scattering of both visible light and X rays at the critical opalescence point will provide polymer chemists with valuable experimental information concerning intermolecular forces in polymeric systems. The results obtained in this study of intermolecular interactions will benefit Air Force scientists in their search for thermally stable polymers as well as low-temperature lubricants for aerospace applications. ★

EARLY BIRD AND TRANSATLANTIC AIRCRAFT

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Radio contact between ground stations and aircraft crossing the Atlantic is sometimes lost when propagation conditions are poor. Use of synchronous satellites as relay stations between ground and aircraft has been suggested as a means to obtain more reliable communications. But propagation, antenna, and power requirements for satellite-aircraft links have been unknown factors.

Since 4 May 1965, AFCRL has evaluated transmissions from the Early Bird synchronous satellite. These studies have led to a better understanding of system parameters. Both the 150-foot radio telescope and the 30-foot radio telescope at AFCRL's radio observatory at Hamilton, Mass., have been used in these studies. Based on data accumulated over a period of several months, it appears that such a communication system is feasible, and that the system will not entail unusual airborne antenna or power requirements.

The FAA has shown a strong interest in the AFCRL study, although the study, as such, is not directly concerned with communications. It is concerned with measuring the electron content of the ionosphere--which is essentially a study of ionospheric density measured by means of variations in the amplitude in a radio signal that has passed through the ionosphere. For such studies, the Early Bird Comsat satellite is an ideal transmitter. Satellite signals of interest are not those associated with the normal video or communications transmissions from the satellite. Instead, the VHF signals (136 Mcps) that carry the satellite's housekeeping information--internal temperature, component performance, and so on--are used.

What makes a synchronous satellite so valuable for ionospheric studies is its unique geometry. It remains in a fixed position relative to the receiver. When low-altitude satellites are used to obtain diurnal variation data, considerable statistical interpolation is necessary because low-altitude satellites cannot provide continuous data for any given location. Synchronous satellites permit the continuous plotting of ionospheric data over one geographic location.

AFCRL used the Early Bird VHF transmissions for ionospheric studies for a five-months' period--until October of this year--when the Early Bird VHF signal was shut off. The discontinuance of these transmissions were extremely disappointing to the AFCRL group which had hoped to obtain data on ionospheric variations for a full-year period. Until Early Bird's VHF transmissions ceased, the group also monitored changes in the ionosphere caused by magnetic-field disturbances, auroral activity, sporadic E, spread F, and solar-noise storms. One purpose of these observations was to accumulate background data needed for detecting ionospheric changes produced by man-made perturbations, such as nuclear blasts in space. Synchronous satellite transmissions are so valuable for propagation and ionospheric studies that special beacons have been proposed for future synchronous satellites.

Although the establishment of an operational aircraft-satellite communications system will obviously entail many measurements geared to obtain data specifically related to communications problems involved, the measurements by AFCRL of amplitude and scintillations of satellite signals appear to place satellite-aircraft communications well within the range of feasibility so far as power-level and amplitude fluctuations are concerned. ★

FIGHT OR FLIGHT-A THIRD CHOICE ? (a physiological response to stress)

CAPT JOEL R. LOWENTHAL, Directorate of Life Sciences, AFOSR

Although man has held up well during eight days of orbital space travel, it is evident from the physiological measurements that have been made on our astronauts that leaving one's planetary home entails certain stresses of a different nature from leaving one's castle in the morning to participate in nonlinear automotive patterns, traffic jams best described by negative Mach numbers, and annually decelerating m.p.h.'s.

Examples of the physiological stresses in space include combinations of sudden acceleration, vibration, extremes of heat and cold, ionizing radiation, weightlessness, and prolonged muscular inactivity. Some of the physical manifestations of these affronts have already been recognized--bradycardia (slowing of the heart) and tachycardia (increased heart rate), hypertension and hypotension, vertigo, impairment of balance, and changes in blood indices. Certainly, longer space voyages extending to weeks and months would also be accompanied by psychological stresses (fear, anxiety, frustration, and irritation) whose causes and effects might both be related to physical parameters.

We are concerned, then, with stress. What causes it? How does it affect our personnel? And how can we cope with it when it impairs performance?

It has long been known that man's so-called "fight-or-flight" response consists of both neurological and hormonal components. Both the hypothalamic region of the

brain and the neighboring pituitary structures have been implicated within the central nervous system, while the adrenal glands are well-known producers of the chemical substances that enable the intact organism to cope with acute emergency situations. The more resistant problem, and indeed the more sophisticated one, has been understanding the integration of these two subsystems and the connections between them.

Neurophysiologists have known for years that the hypothalamus has exerted some regulatory effect on the anterior portion of the pituitary gland. The latter secretes ACTH (adrenocorticotrophic hormone), which in turn stimulates the adrenal glands to produce the vitally needed steroid hormones. How these steroids manage to enhance man's fight-or-flight potential is really not very well understood either, but our present concern is not with this particular puzzle. We set out to discuss the interaction between hypothalamus and pituitary.

Earlier in this century two regulatory theories vied for prominence: one school claimed that there were efferent neuronal connections between the hypothalamic nuclei and the secretory cells of the anterior pituitary, while others hypothesized that hormones produced in the hypothalamus were transported to the pituitary via the blood stream. Work in recent years has validated the hormonal theory, and Dr. Paul L. Munson, an AFOSR grantee at Harvard University, has been trying to purify a hormone that might well be the connecting link. The substance, called "hypothalamic secretory factor for ACTH" (HSF-ACTH), is extremely difficult to isolate in quantity and is almost equally difficult to assay once it is in the test tube.

The biological assay involves the intravenous injection of HSF-ACTH into rats and the subsequent measurement of the fall in their adrenal ascorbic acid. The decrease in ascorbic acid is a generally accepted quantitative index of ACTH secretion by the organism. Hence, the more HSF-ACTH there is in a sample, the more ACTH will be secreted by the pituitary, and the larger will be the fall in adrenal ascorbic acid. The major problem, however, is that it seems likely that preparations of HSF-ACTH made to date might be contaminated with slight amounts of ACTH, and this might consequently throw off the estimates of purification. In other words, how much, if any, HSF-ACTH has been obtained?

Dr. Munson and his colleagues are attempting to iron out these wrinkles. Should they succeed, the addition of HSF-ACTH to man's growing collection of on-the-shelf hormones might help future astronauts to tolerate space travel better, even if it never helps his earth-bound counterpart to endure rush-hour traffic with less anguish, and to smile cheerfully while his $50-deductible fenders are being violated. ★

"SOUND CHEMISTRY" AND CHEMICAL SOUNDNESS

DR. ALFRED WEISSLER
Directorate of Chemical Sciences, AFOSR

The chemical soundness of molecules under various disruptive influences is a subject of much practical and theoretical interest. Molecules can be broken apart not only by high temperatures and nuclear radiation, but also by intense sound waves. The latter has been given explicit recognition, in the Russian aerospace program, as a cause of possible malfunctions of materials and pilots.

"Sound chemistry" or "sonochemistry" are the names given to the study of molecular disintegrations caused by exposure to sound or ultrasound waves. Most of the previous work in this field has been concerned with the sonochemical reactions of water or of aqueous solutions. It was found, for example, that hydrogen peroxide is produced by ultrasonic irradiation of pure water, and that hemoglobin is rendered physiologically useless by conversion into methemoglobin, which

then undergoes further degradation. Such changes are due to ultrasonic cavitation of water containing air or other dissolved gas; adiabatic compression in the collapsing cavities produces local temperatures of the order of 10,000°K.

Under the auspices of AFOSR, sonochemical research has just been extended into a new area. For the first time, it was shown that pure organic liquids (such as acetonitrile or carbon tetrachloride) undergo sonochemical decomposition even in the absence of water. This result was achieved by a team consisting of Prof. Michael Anbar (an AFOSR grantee) and Israel Pecht of the Weizmann Institute of Science in Israel and the author of this article during his five weeks of work in Anbar's laboratory.

Acetonitrile was chosen for detailed study because of its wide use in physical chemistry as a nonaqueous solvent. After irradiation of acetonitrile in an argon atmosphere with 800-kilocycle ultrasound, analysis of the products by gas chromatography showed that nitrogen, methane, and hydrogen were formed in molar ratios of 1:2:4, respectively (Fig. 1). The analytical results were confirmed by mass spectrometry.

When an atmosphere of oxygen was used instead of argon, the sonolysis of acetonitrile no longer gave either hydrogen or methane. In their place, new products appeared: carbon monoxide, carbon dioxide, and water, in molar proportions of 6:2:1. This was demonstrated by comparative experiments with ordinary oxygen and oxygen-18 isotopic tracer, using mass-spectrometer analyses. The Weizmann Institute is uniquely suited for this research since it houses the world's only separation plant for the production of high-purity oxygen-18.

Further experiments showed that pure anhydrous carbon tetrachloride also undergoes ultrasonic breakdown with the production of elemental chlorine, particularly when the back-reaction is suppressed by adding a little butyl iodide as scavenger of the CCl_3 fragments.

A path has thus been opened for exploring the sonochemistry of nonaqueous liquids and solutions. This new field may be of interest not only as fundamental science, but also to those concerned with novel syntheses of rocket fuels or with the deterioration of lubricants and hydraulic fluids under vibrational stresses. ★

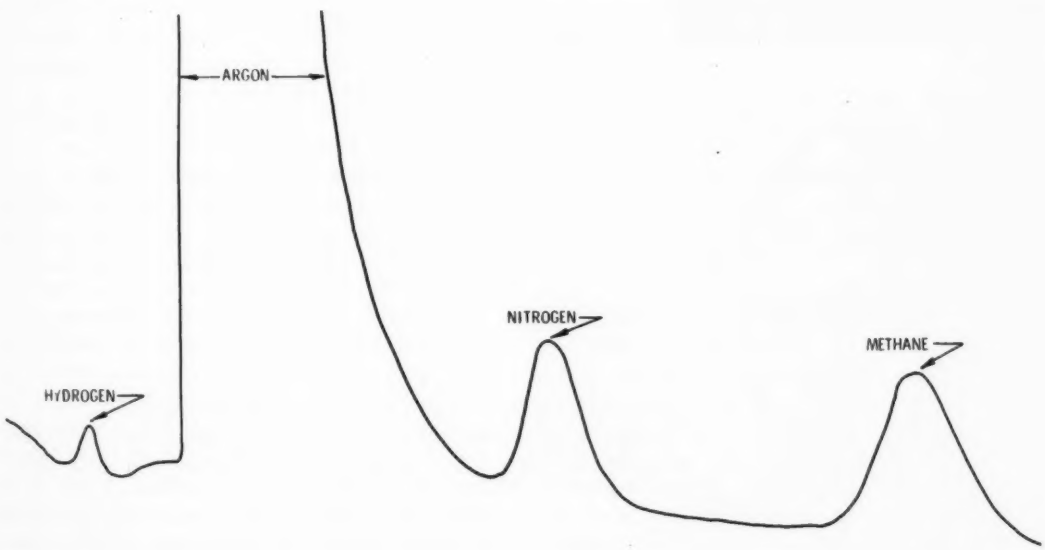

Figure 1 Gaseous sonolysis products of acetonitrile under argon, as shown by gas chromatography with helium carrier and thermal conductivity detector.

A CLASS OF PERIODIC ORBITS IN THE RESTRICTED THREE-BODY PROBLEM

1ST LT ALLAN F. SCHANZLE
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Our recent ability to orbit artificial celestial bodies has led to a renewed interest in the much older subject of Celestial Mechanics. Obtaining meaningful results, however, is no simple task, since the differential equations describing the motion of n bodies under the influence of a purely gravitational field have no known general analytical solution. Of course, one can, by means of a digital computer, integrate the equations numerically. However, such a method exhibits several disadvantages, namely:

1. Round-off errors for long integration times;
2. Truncation errors due to numerical techniques; and
3. The requirement to compute intermediate points which are not necessarily desired.

One is thus confronted with the problem of choosing between the solving of the exact problem approximately (analytically using infinite series, or numerically using integration schemes), or the solving of an approximate problem exactly (the trivial two-body problem).

Perhaps the most interesting and the simplest nontrivial problem in classical Celestial Mechanics is the Restricted Three-Body Problem. This problem is characterized by determining the motion of an infinitesimal mass under the influence of two finite masses which move in an assumed ellipse or circle about their center of mass. An important recent application of the Restricted Problem has been to the determination of trajectories for lunar probes. In this case, the infinitesimal mass is the space probe, and the two finite masses are the Earth and Moon. All but a few special cases of these investigations utilize numerical integration methods, since no general solution has yet been found even for this relatively simple model. The primary drawback to these studies is that they represent, with reasonable accuracy, the real system for only a short period of time, since the effect of the Sun is neglected.

There exists in the solar system another configuration which better lends itself to the application of the Restricted Problem. Between the orbits of Mars and Jupiter there are many small masses called minor planets or asteroids. Several of these natural celestial bodies, called the Trojan group of asteroids, exhibit a particular type of motion which can be closely represented by the Restricted Problem when the two finite masses are Jupiter and the Sun, and the infinitesimal mass is the Trojan. The primary assumption which limits this application of the Restricted Problem lies in neglecting the effects of Saturn. The perturbations due to Saturn, however, are much less than the corresponding assumption (perturbations due to the Sun) in the Earth-Moon system.

A particular case of the Jupiter-Sun Restricted Three-Body Problem has recently been investigated by the author. The original objective of this particular investigation was to determine, via numerical integration methods and under the assumptions of the Restricted Problem, if it is possible that some of the Trojans could be escaped outer satellites of Jupiter. This question, unfortunately, remains unanswered, due to unforeseen circumstances which arose as a result of the particular method of attack and which put an unrealistic upper bound on the required computer time. The work has not, however, been in vain, since a multitude of periodic orbits of the horseshoe type have been discovered.

The stability of these horseshoe orbits has been investigated. The question of the stability of these orbits is fundamentally the following: assuming a small perturbation to the periodic Trojan orbit as determined under the assumptions of the Restricted Problem, what will be this perturbed Trojan's final motion as time approaches infinity? That is, will the perturbed asteroid be near the corresponding

unperturbed periodic orbit (stable), or will it tend to go to infinity (unstable)? Definitive results on the stability were obtained. In particular, it has been found that one orbit included in the particular class of orbits investigated, which a previous investigator had claimed to be stable, was in fact unstable. The results also pinpoint the incorrect reasoning which had led to the conclusion of a stable orbit by the previous investigator.

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Schanzle, 1/Lt Allan F., "A Class of Periodic Orbits in the Restricted Three-Body Problem," SRL 65-3, The Frank J. Seiler Research Laboratory, OAR, USAF Academy, Colo., 1965.

PROFILES

First Lieutenant Allan F. Schanzle was assigned to the Aerospace Mechanics Division, The Frank J. Seiler Research Laboratory, in July 1963. Prior to this assignment, he attended the University of Cincinnati where he was graduated from the College of Engineering with the degree of Aeronautical Engineer (1959). Continuing his studies at Cincinnati in the Department of Astronomy, he was awarded the degrees of M.S. (1961) and Ph.D. (1964) in Celestial Mechanics. Lieutenant Schanzle is a member of the American Astronomical Society and the author of the article, "A Class of Periodic Orbits in the Restricted Three-Body Problem," appearing in this issue of the OAR Research Review.

1st Lt Robert Poplawski was assigned to the Thermomechanics Research Laboratory, Aerospace Research Laboratories, in June 1964 after having been graduated from the Institute of Technology with an M.S.A.E. He received his B.S. (Mechanical Engineering) from the University of Massachusetts in 1962. At the present time, he is working in the area of the aerodynamics of vortex flows. In this issue of the OAR Research Review, Lt Poplawski is co-author of the article, "Aerodynamic Effects of Secondary Flows in Confined Vortices."

aerodynamic effects of secondary flows in confined vortices

1ST LT ROBERT POPLAWSKI and
1ST LT ALFRED C. PINCHAK
Thermomechanics Research Laboratory, ARL

I. Introduction

Vortex flows in confined regions have been of considerable interest for some time. Applications of such flows range from particle centrifuging and dissimilar gas separation to the production of heating or refrigerating effects as found in the Ranque-Hilsch tube. Flow fields designed for the above applications must possess high rotational velocities, and, in the former cases with which this paper deals, a low turbulence level in the vortex core region. In addition, the secondary-flow pattern in the vortex tube must deliver the mass flow to the high speed core region where gas or particle separation occurs, and then prevent subsequent remixing of the enriched and depleted flows.

In conventional vortex tubes, high rotational velocities may be obtained. However, the secondary-flow pattern transports large fractions of the total flow to end-wall boundary layers. As a result, a substantial portion of the flow is not carried to the core or separation region. This limits separation capabilities to particle sizes of the order of 10 microns. A vortex or swirl chamber possessing a secondary-flow pattern which eliminates many of the undesirable features of the conventional vortex tube is briefly described here along with some recent experimental results. Indications are that this new chamber will allow separation of particles up to two orders of magnitude smaller than those separated by conventional chambers. The secondary-flow pattern of the swirl chamber is considered in some detail.

II. Method of Investigation

A schematic of the high-pressure chamber showing the internal geometry of the device can be seen in Figure 1. Unlike conventional vortex tubes, the present device is symmetrical about a center plane, and has end-wall injection ports. There are a total of 48 1/16-inch diameter nozzles in 8 groups, injecting fluid tangentially at 4 radii. The mixing radius of all jets is slightly smaller than the local chamber radius. In addition to the chamber exhaust found on conventional vortex devices, the present chamber has provisions for mass extraction at the outer radius, called the exit of the device. Figure 1 also shows the location of the wall (P_w), the centerline ($P_{\mathcal{L}}$), and the exhaust cylinder taps ($P_{e.c.}$). In order to obtain the radial pressure profiles and thus determine the local Mach number distribution, a pressure distribution "spoke" was placed in the geometric center plane of the chamber. In other tests, a miniature "anemometer" was utilized for rotational speed measurements. The anemometer was suspended on the axial centerline in the plane of symmetry of the chamber through the use of four 0.014-inch diameter wires stretched radially across the chamber. These and other details concerning the experimental apparatus may be found in Reference 1. Table 1 presents the range of operating parameters of the swirl chamber.

Table I

Operating Parameters for the High-Pressure Swirl Chambers

Working Fluid	Air
Inlet Stagnation Pressure	0-300 psig
Inlet Stagnation Temperature	~ 50°F.
Inlet Mass Flow	0.05-0.90 lb_m/sec
Mass Flow Ratio ($\dot{m}_{exit}/\dot{m}_{in}$)	0-0.60
Pressure Ratio ($Pw/P_{\mathcal{L}}$)	1-45
Maximum Tangential Mach Number	~ 1.2

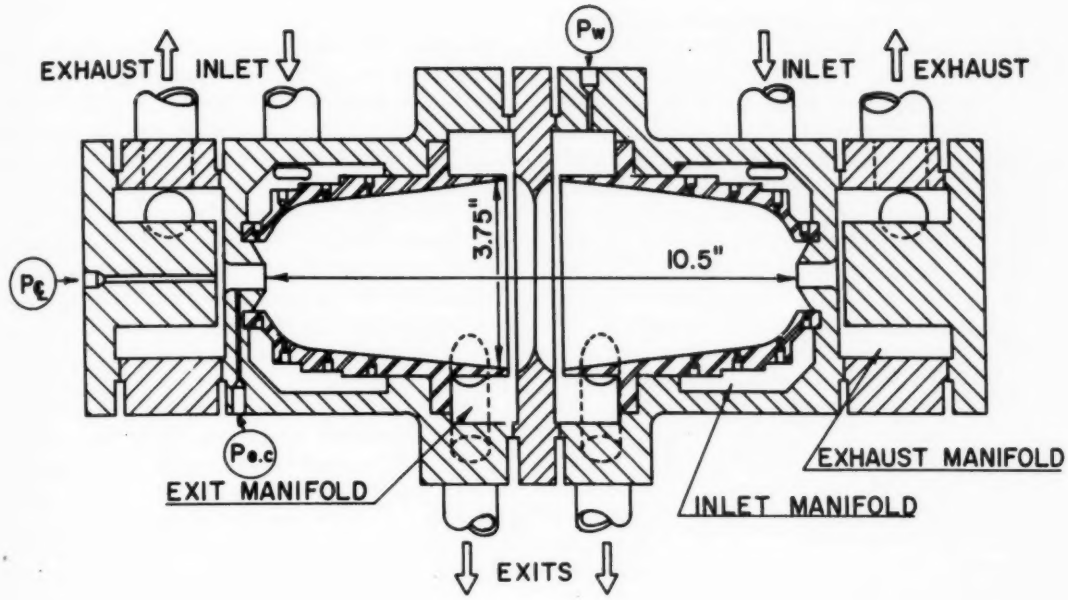


FIG. 1 INTERNAL GEOMETRY HIGH PRESSURE SWIRL CHAMBER

III. Results

A. Tangential Velocity Measurements: Figure 2 presents a typical tangential Mach number distribution as determined from the radial pressure distribution. The presence of the pressure distribution "spoke" resulted in lower over-all pressure ratios ($P_w/P_{\mathcal{L}}$), and thus it is probable that the measured Mach numbers were reduced from the corresponding condition with no "spoke" present. As Figure 2 indicates, opening of the exit (increasing $\dot{m}_{exit}$) results in a lower maximum Mach number which simultaneously occurs at a larger radial distance from the centerline. In this respect, the reversed-flow vortex chamber exhibits the same behavior as conventional vortex tubes (2). Due to the method of injection in the reversed flow chamber, a reduction in maximum Mach number is expected. However, the value of the maximum Mach number obtained here compares favorably with the maximum values of 1.2 and 1.4 obtained, respectively, by Pivirotto (2) and Keyes (3) in conventional vortex tubes.

One of the unique tasks of the current research has been the development of a small anemometer to measure the rotational speeds in the vortex core. Speeds up to 475,000 rpm have been measured prior to bearing failure. A light beam is intercepted by the rotating anemometer, and the resulting "chopped" light signal is detected by a photocell. A CRO and an electronic counter monitor the output of the photocell. Currently, the anemometer is being redesigned in an attempt to measure rotational speeds in excess of 1×10^6 rpm. This anemometer has, thus far, been able to record rotational speeds up to 475,000 rpm prior to failure.

B. The Secondary-Flow Pattern: In order to enhance the separation capability of a vortex chamber, the secondary-flow pattern (meridian flow) must be reversed, as shown in Figure 3. This flow reversal insures that nearly all the mass flow passing out the exhaust goes through the core region where

strong centrifugalization occurs. To produce this radial outflow near the exhaust region, it is necessary to inject high-velocity air on the end walls of the chamber. Fluid injection at these inner radii is costly because the wall torques due to skin friction vary inversely with the radius for the case of a free vortex velocity distribution in the chamber. The centrifugal force acting on the injected fluid must exceed the local radial pressure gradient if radial outflow is to occur, $\rho \frac{V_t^2}{r} >> \frac{\partial p}{\partial r}$. In order to continue the flow reversal radially outward, it is necessary to inject fluid at the larger radii. The excess angular momentum added at each radial position must compensate for a suitable portion of the wall skin friction. In addition, the injected flow must maintain the condition of constant angular momentum per unit mass in the total reversed flow. As a result, the total angular momentum flux of the

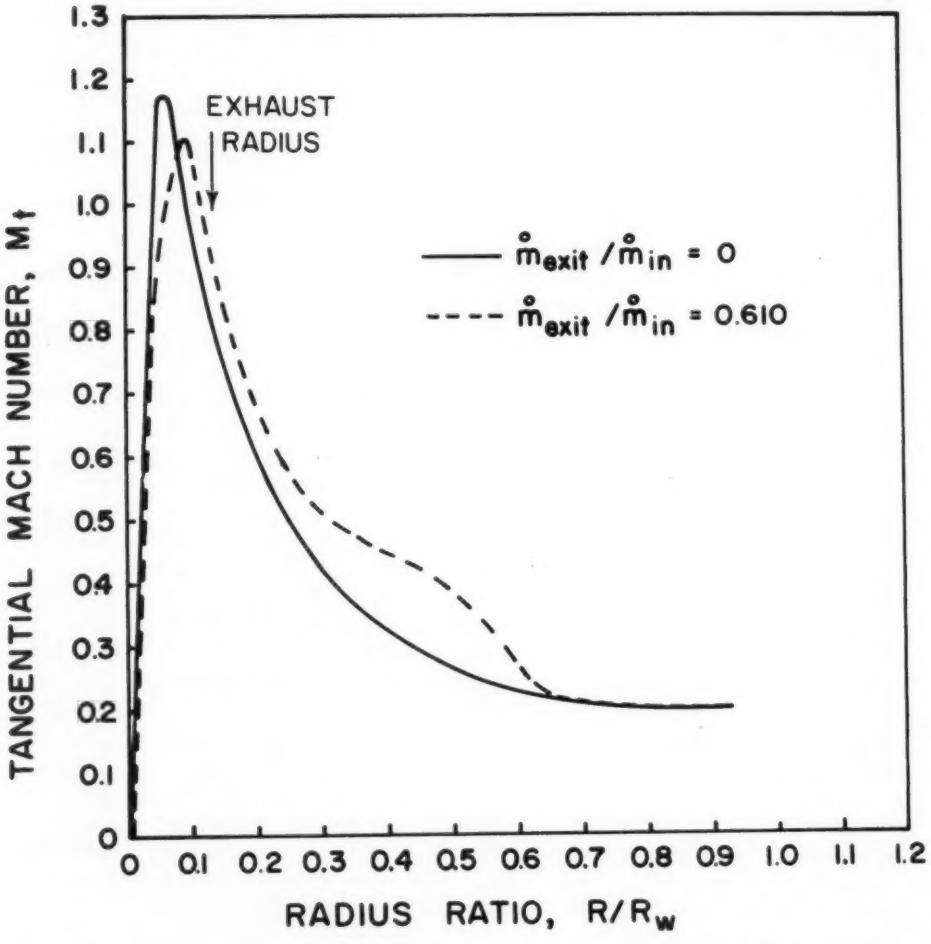


FIG. 2 TYPICAL TANGENTIAL MACH NUMBER PROFILES AS A FUNCTION OF THE MASS FLOW SPLIT FOR A FIXED INLET PRESSURE OF 114.3 PSIA

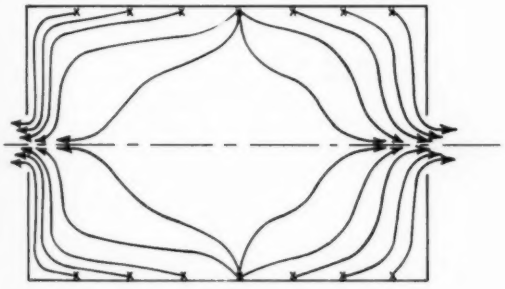
injected fluid must be greater than the total skin friction torque acting on the internal surfaces of the chamber. Thus, the local skin friction losses and the circulation of the main vortex fix the requirements for the end-wall injection.

If the above conditions are met, the flow is reversed on the end walls of the chamber. The selection of the number and location of the injection ports is based on the geometry of the chamber, an assumed skin friction law, and an apriori velocity profile selected for the device (4).

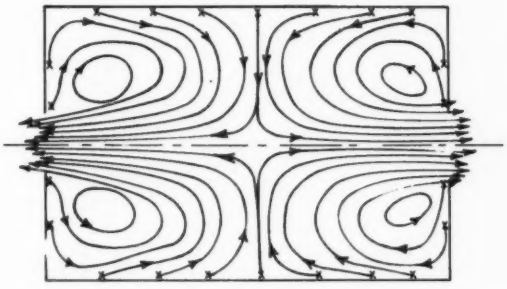
The use of discrete rows of injection ports at various radii creates a localized, high-energy flow field which tends to prevent radial inflow in regions near the wall. This localized high-speed fluid ring is termed a "velocity" or "boundary-layer fence". A sketch of this type of end-wall flow is shown in Figure 4(a).

Two distinct flow regions are noted in the region between two successive injection ports. In the "outer" region, the bulk of the injected flow is moving radially outward. In a thin layer near the wall, the flow must move radially inward as the tangential velocities in this boundary layer are not sufficient to resist the radial pressure gradient. When this boundary-layer flow reaches the adjacent injection port (at a smaller radius), the "velocity fence" re-energizes the major portion of this boundary-layer flow and recirculates it radially outward. Because of the discrete location of injection ports, a small portion of this flow "leaks" through the "fence" and enters the region inside the first injection port.

In the region of the minimum injection radius (R_i), a portion of the high-energy air traveling radially inward cannot leave the chamber until some of its energy is dissipated. The fluid accomplishes this by forming a cusp in the region of the exhaust (see Figure 4.b.). This cusp formation has been extensively studied by Rosenzweig, Lewellen and Ross (5, 6, 7). The cusp "gives up" some of its energy by driving the outer vortex regions of the flow. Mass ejection or cusp formation at the minimum radius is dictated by the exhaust hole geometry which acts as a surface discontinuity to the end-wall boundary-layer flow. Mass ejection from the boundary layer can also occur at



COVENTIONAL VORTEX TUBE
INJECTION ALONG TUBE
PERIPHERY ONLY.



REVERSED FLOW VORTEX TUBE
INJECTION ALONG BOTH PERIPHERY
AND END WALLS.

Note: SUPERIMPOSED TANGENTIAL VELOCITIES NOT INDICATED

FIG. 3 SECONDARY OR MERIDIAN FLOW PATTERNS IN VORTEX TUBES

radial distances greater than the exhaust hole (Figure 4.b.) if the main flow's circulation decreases sufficiently with decreasing radius. The phenomenon of boundary-layer ejection has been investigated both analytically, and verified experimentally (6, 7). It should be noted that it was not possible to visually detect a cusp formation in the present experiments (8). However, this does not preclude the possibility of cusp formation in the region near the minimum radius of injection.

IV. Conclusions

By properly programming the injected flow in a vortex chamber, the secondary flow may be forced radially outward in regions near the end walls. The reversal of the secondary flow does not appreciably affect the magnitude of the maximum tangential Mach numbers obtained. As with conventional vortex tubes M_{tmax} lies somewhere in the range from 1.1 to 1.5.

Apparently, the maximum rotational velocities in the reversed-flow swirl chamber are limited by the same mechanisms which exist in conventional vortex tubes. Separation of dissimilar gases or small particles will thus be enhanced in the aforementioned swirl chamber by the improvement of the secondary-flow pattern rather than by increases in the maximum rotational velocity.

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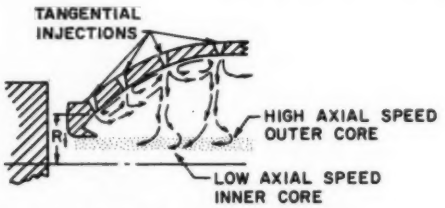
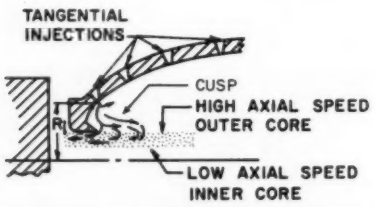


(a) POSSIBLE FLOW DIRECTIONS FOR WALL REGIONS GREATER THAN "R_i"



(b) POSSIBLE FLOW DIRECTIONS FOR WALL REGIONS LESS THAN "R_i"

FIG. 4 POSSIBLE AXIAL AND RADIAL FLOW PATTERNS WITHIN THE HIGH PRESSURE CHAMBER

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